Project Title: Processes of World-Class Ore Deposit Formation

Statement of Problem

A goal of the USGS Minerals Program is to increase knowledge of world-class ("giant") ore deposits (Goal 3, Element 3.1, Activity 3.1.2, Subactivity 3.1.2.1). World-class ore deposits are the largest 10% of deposits as ordered by metal content (Singer, 1995). The world-class deposits dominate the potential supply of many metals and are, therefore, of greatest importance (1) in an assessment of undiscovered mineral resources, (2) to the supply of minerals in the United States, and (3) to minerals exploration organizations. Therefore, for the USGS to better forecast at regional, national, and global scales the likelihood of as-yet undiscovered world-class deposits, it is necessary to understand how these deposits formed, why they grew to such a size, and what criteria may be used to forecast their occurrence.

Although the economic geology research community has recognized the importance of understanding how world-class deposits form (e.g., Clark, 1995), as summarized by Sillitoe (1997), no published studies have successfully identified a unique set of criteria that either allow the a priori discrimination between world-class and sub-world-class deposits or the forecasting of the location of undiscovered world-class deposits. The point of view and research strategy used in this project differ in significant ways from other USGS and non-USGS investigations. Based on results from previous USGS investigations by this research team, we contend that ore formation cannot be understood if (1) fluid flow is not considered as a coupled phenomenon together with thermal, mechanical, chemical, and hydraulic processes, (2) processes at the site of ore deposition are not considered essential to producing supersaturated metal concentrations in hydrothermal solutions, and (3) if no comparison is made of the structural, geometric, and thermal-chemical attributes of world-class and sub-world-class deposits at different spatial scales. Our experience suggests that our approach can provide the spatial and analytical data and understanding needed to predict probable locations of world-class hydrothermal ore deposits.

Objectives

The USGS Minerals Program seeks to increase knowledge about ore-deposit genesis (Subactivity 3.1.2.1), use this knowledge to improve methodologies for mineral-resource assessment (Subactivity 3.1.2.2), and apply these methodologies at different spatial scales from local and national (Element 3.4, Subactivity 3.4.2.2) to global (Element 3.2, Activity 3.2.2). The principal goal of this project is to enhance the ability of USGS scientists to forecast the likelihood of as-yet undiscovered world-class mineral deposits at different spatial scales, with particular emphasis on epizonal base- and precious-metal hydrothermal deposit types typically found in subduction-boundary zones. Of highest priority are porphyry Cu, polymetallic veins and replacements, and epithermal Au-Ag-base metal systems. To work towards the principal goal, the project focuses on the following interrelated objectives: (1) What are the regional tectonic and structural systematics of convergent plate margins?; (2) How do the tectonics and structural geology of subduction-boundary zones change in time and space?; (3) What tectonic and structural environments most effectively focus coupled fluid flow and deformation?; (4) What is the nature and pattern of fracturing in different parts of fault and intrusive rock systems? (5) What understanding may be gained about feedback mechanisms between fluid flow, ore formation, and deformation using, for example, stable isotope geochemistry and chemical patterns in veins and minerals? (6) What, at different spatial scales, are the tectonic and structural geologic settings of world-class and sub-world-class ore deposits?; (6) What are the similarities and differences between world-class and sub-world-class ore deposits?

Relevance and Impact

The USGS is currently conducting a global assessment of undiscovered mineral resources including copper and gold. At least 71% of the known Cu resource occurs in association with igneous rocks. World-class deposits of Cu account for 84% of the total known Cu resource (Singer, 1995). Thus, a greater understanding about how porphyry Cu deposits are localized and form will significantly improve mineral-resource assessments and assist minerals exploration. Approximately 54% of all non-placer Au is clearly related to igneous rocks (Singer, 1995). If deposits spatially associated but of uncertain genetic relation to igneous rocks (e.g., Mother Lode, Carlin) are included, then 99% of all non-placer Au is related to igneous rocks. Significant Au resources occur in epithermal and porphyry Cu type deposits. Therefore, knowing how and why world-class epizonal ore deposits in subduction-boundary zones form will contribute greatly to the development of assessment methodologies that improve quantitative forecasts of undiscovered world-class deposits. Potential benefits to the USGS Minerals Program include providing knowledge that (1) can assist a greater number of USGS scientists to carry out quantitative mineral-resource assessments; (2) aids in the quantitative delineation of tracts of land permissive for the occurrence of specific deposit types; (3) allows the subdivision of permissive tracts into regions of differing favorableness; and, (4) allows the prediction of where, within permissive tracts, world-class deposits can occur and where sub-world-class deposits are more likely.

Strategy and Approach

The research strategy to be used in this project is based on the scientific results achieved principally in the (a) Coupled Thermal, Mechanical, Chemical, and Hydraulic Phenomena in Ore Formation and (b) Advanced Mineral Resource Assessment Methods projects (e.g., Anderson and others, 1998; Berger and others, 1998, 1999, 2000, 2003a, 2003b; Berger and Drew, 2001; Henley and Berger, 2000; Phillips and others, 2002). In the 'thermal-mechanical-chemical' project, fundamental relationships were identified linking the tectonic and structural evolution of the shallow crust to magmatic and hydrothermal fluid flow. Further, there is a growing body of evidence that ore-forming environments are structurally, thermally, and chemically dynamic, and the interaction of hydrothermal fluids with deposit-site specific phenomena in the "creation" of high-grade, ore-forming solutions is critical.

As a framework for understanding the localization of ore-forming environments, this project contributes to the knowledge of the tectonic and structural evolution of subduction-boundary zones, with particular emphasis on ones that contain world-class ore deposits. Particular emphasis is being placed on strain partitioning between different structural domains in subduction-boundary zones and as well as within domains, especially those elements that most effectively localize fluid flow and focus it into laterally segmented flow compartments. This project also links processes at different spatial scales to elucidate the feed-forward and feedback mechanisms critical to ore formation and the scale at which different mechanisms are important. The attributes that allow the common classification of ore deposits into classes do not discriminate world-class and sub-world-class deposits. Therefore, it is necessary to conduct a comparative analysis of world-class and sub-world-class deposits at different spatial scales to determine which geologic and geochemical characteristics can distinguish the two categories. Our research to date suggests that strain partitioning and its effect on permeability is a critical process in ore formation and that world-class and sub-world-class deposits differ in the displacement transfer that occurred during mineralization, the duration of strain focusing vis-a-vis magma production, and the extent to which slip was paritioned over a region larger than the site of a deposit.

A variety of tools are inherently important to our investigation. High-quality framework geology, structural geology, and tectonic maps are the foundations for our investigations and field work is done where needed to meet our quality standards. High-quality aeromagnetic data serve as a mapping tool of the structure and geology of the surface and subsurface, and to elucidate structural relations of importance but obscurred by surface relationships and/or exposures. Gravity data are used in conjuction with aeromagnetic data to map crustal-scale fracture systems, geologic bodies with common characteristics, and assist in understanding the tectonic and structural evolution of mineralized areas and regions. These geophysical data are supplemented, where needed, using other techniques (e.g., magnetotellurics). Thermochronology is essential to solving stratigraphic and structural problems as well as testing the probable relations between different geologic observations. It is also used in conjunction with stable isotope and trace element analyses to relate alteration and deformation processes, evaluate how diverse alteration types relate temporally and genetically, when and how ore bodies form within fracture networks, and any possible role that climate and topography may play in the genesis of epizonal ore deposits.

References Cited

Anderson, R.E., Berger, B.R., and Snee, L.W., 2000, Heterogeneous uplift and tilting of basement blocks in an extensional tectonic setting, Wassuk Range-Coal Valley area, Nevada: Geological Society of America, Abstracts with Programs, v. 32, no. 7, p. 43.

Berger, B.R., Goldhaber, M.B., Hildenbrand, T.G., and Wanty, R.B., 1998, Origin of Carlin-style gold deposits: Coupled regional fluid flow, core-complex related extension, strike-slip faults, and magmatism: Geological Society of America, Abstracts with Programs, v. 30, no. 7, p. 371.

Berger, B.R., Snee, L.W., and Tingley, J.V., 1999, Implications of new structural and 40Ar/39Ar data on hydraulic evolution of epithermal veins and ore formation, Aurora and Bodie mining districts, Nevada-California: Geological Society of America, Abstracts with Programs, v. 31, no. 7, p. 94.

Berger, B.R., Phillips, J.D., and Ridley, W.I., 2000, The role of basement structures in the localization of Laramide mineralization: Examples from the Patagonia Mountains, south-central Arizona: Geological Society of America, Abstracts with Programs, v. 32, no. 7, p. 393.

Berger, B.R., and Drew, L.J., 2001, The effects of evolving structural systems and tectonics on compartmentalization of fluid flow and ore deposition in epithermal hydrothermal systems, western Great Basin: Geological Society of America, Abstracts with Programs, v. 33, no. 6, p. 420.

Berger, B.R., Tingley, J.V., and Drew, L.J., 2003a, Structural localization and origin of compartmentalized fluid flow, Comstock Lode, Virginia City, Nevada: Economic Geology, v. 98. p. 387-408.

Berger, B.R., King, T.V.V., Morath, L.C., and Phillips, J.D., 2003b, Utility of high-altitude infrared spectral data in mineral exploration: Application to northern Patagonia Mountains, Arizona: Economic Geology, in press.

Clark, A.H., 1995, Giant ore deposits II: Controls on the scale of orogenic magmatic-hydrothermal mineralization: Proceedings of the Second Giant Ore Deposits Workshop, Department of Geological Sciences, Queen's University, Kingston, Ontario, 753 p.

Henley, R.W., and Berger, B.R., 2000, Self-ordering and complexity in epizonal mineral deposits: Annual Reviews of Earth and Planetary Sciences, v. 28, p. 669-719.

Phillips, J.D., Berger, B.R., Sampson, J.A., Webring, M.W., and Anderson, R.E., 2002, The nature of basins in the transition zone from Sierra Nevada to Basin and Range as revealed by gravity, geology, magnetotellurics, and high-resolution aeromagnetic data: Geological Society of America, Abstracts with Programs, v. 34, no. 6, p. 452.

Sillitoe, R.H., 1997, Characteristics and controls of the largest porphyry copper-gold and epithermal gold deposits in the circum-Pacific region: Australian Journal of Earth Sciences, v. 44, p. 373-388.

Singer, D.A., 1995, World-class base and precious metal deposits- A quantitative analysis: Economic Geology, v. 90, p. 88-104.